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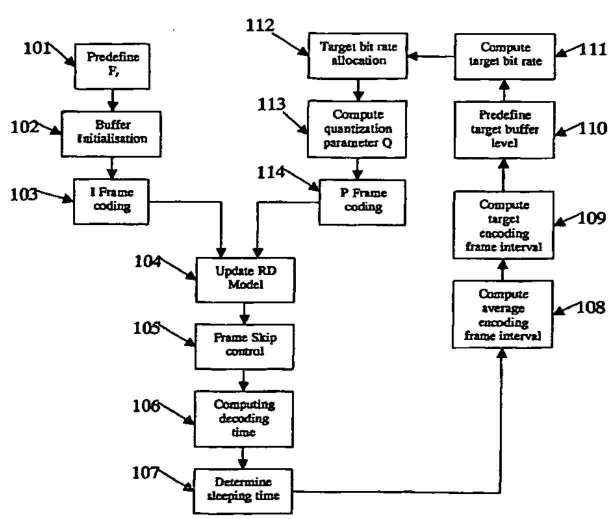

(57) Abstract: A method for rate control for encoding video sequence, wherein the video sequence comprises a plurality of Group Of Pictures, wherein each Group of Picture comprises at least and I-frame and an Inter-frame, the rate control method comprising the following steps for the encoding of the. Inter-frame in the Group of Picture: determining a desired frame rate based on an available bandwidth of a channel for transmitting the video sequence and an available computational resources for the encoding process; determining a target buffer level based on the desired frame rate and the position of the Inter-frame with respect to the I-frame; and determining a target bit rate based on the target buffer level and the available channel bandwidth, wherein the target bit rate is used for controlling the rate of encoding the video sequence.

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A METHOD AND AN APPARATUS FOR CONTROLLING THE RATE OF A VIDEO SEQUENCE; A VIDEO ENCODING DEVICE

This invention relates to a method and an apparatus for controlling the rate for encoding a video sequence and a video encoding device, wherein the available channel bandwidth and computational resources are taken into account.

Background of Invention

Rate control plays an important role in the encoding of live video over a channel with a limited bandwidth, for example over an internet or a wireless network, and has been widely studied by many researchers. Existing results on rate control as disclosed in [1], [2], [3], [4] are based on the assumption that the computational resources are always sufficient and hence, the desired encoding frame rate is always guaranteed.

However when a live video is encoded via software under a multi-task environment, the computational resources of the Central Processing Unit (CPU) may not always be sufficient for the encoding process. This is due to the fact that the computational resources of the CPU may be taken up by other processes having a higher priority. In real time video coding systems, encoded bits are stored in a buffer before they are transmitted over the network to a decoder. When insufficient computational resources are allocated for the encoding process, the actual encoding frame rate is less than the desired frame rate, and the number of generated bits stored in buffer is too low. As a result, the available

channel bandwidth is wasted. This phenomenon is especially common when the video encoding process is implemented on a handheld device with limited computational capabilities.

Also, most existing rate control methods are focused on the case that the available channel bandwidth for the transmission of the video is constant. However, when the live video is transmitted over a limited bandwidth channel like the Internet or a wireless network, the available channel bandwidth for the transmission of the video usually varies over time. When the available bandwidth of the channel decreases, the number of bits in the buffer accumulates. When the number of bits in the buffer is too large, the encoder usually skips some frames to reduce the buffer delay and to avoid buffer overflow. Frame skipping produces undesirable motion discontinuity in the video sequence.

A recent teaching in reference [5] discloses a rate control method that can adapt the encoding rate to the varying available bandwidth. The rate control method uses a fluid-flow model to compute a target bit rate for each frame of the video sequence. However, the rate control method as disclosed in [5] does not take into account the available computational resources. Moreover, the total number of bits allocated to each Group of Pictures (GOP) are distributed to each P frame in the GOP evenly.

Summary of the Invention

It is an object of the invention to provide a rate control method that is suitable for live video encoding process with

varying computational resource and varying available bandwidth.

The object is achieved by a method for controlling the rate for encoding a video sequence, wherein the video sequence comprises a plurality of Group Of Pictures (GOP), wherein each Group of Picture comprises at least an I-frame and an Inter-frame, the method comprising the following steps for the encoding of each Inter-frame in the Group of Picture; determining a desired frame rate based on an available bandwidth of a channel for transmitting the video sequence and on available computational resources for the encoding process; determining a target buffer level based on the desired frame rate and the position of the Inter-frame with respect to the I-frame; and determining a target bit rate based on the target buffer level and the available channel bandwidth, wherein the target bit rate is used for controlling the rate for encoding the video sequence.

A GOP of the video sequence is assumed to comprise an I-frame (an Intra-frame, i.e. a frame, which is completely encoded without performing motion estimation and motion compensation) and a plurality of P-frames (Predictive-frames, i.e. frames which are encoded using motion estimation and motion compensation) or B-frames (Bi-directional-frames, i.e. frames which are encoded using motion estimation and motion compensation from two adjacent Intra-frames) as Inter-frames. The bits are allocated to the I-frame based on its complexity, and the bits are allocated to each Inter-frame, preferably of each P-frame, using the rate control method according to the invention.

Although the rate control method, in particular the determining of the target buffer level and the corresponding target bit rate, is performed preferably on the P-frames of the GOPs, it should however be noted that the rate control method according to the invention may also be performed on the B-frames.

When encoding the Inter-frame, preferably the P-frame, a desired frame rate is first determined based on the available channel bandwidth and the available computational resources for the encoding process. The desired frame rate does not remain constant, but changes adaptively for each Inter-frame depending on the available channel bandwidth and the available computational resources.

When the available computational resources are insufficient to achieve the desired frame rate, the encoded bits accumulated in the encoder buffer is therefore low, resulting in buffer underflow and wastage of channel bandwidth. A target buffer level is therefore predefined to prevent buffer underflow by taking into account the available computational resource for the encoding process.

The target buffer level defines how the total number of bits which are allocated to the GOP are to be distributed to each Inter-frame (preferably P-frame) of the GOP, i.e. the budget for each Inter-frame. However, there is normally a difference between the budget of each Inter-frame and the actual bits used by it. To ensure that each Inter-frame, and hence each GOP, uses its own budget, the target bit rate for each Inter-frame is computed. The target bit rate is computed using a fluid flow model and linear system control

theory, and taking into account the target buffer level and the available channel bandwidth.

The desired frame rate is determined by determining a target encoding time interval for the Inter-frame, preferably the P-frame, i.e. the time needed for encoding the Inter-frame. The target encoding time is inversely proportional to the desired frame rate, and is determined based on the available bandwidth and also preferably based on an average encoding time. The average encoding time interval for encoding the Inter-frame is proportional to the computational resources, and hence is indicative of the available computational resources. The available bandwidth can be estimated using the method disclosed in [6].

The target encoding time interval for encoding the Inter-frame is determined using the following equations:

$$T_{fi}(n) = A_1 * T_{fi}(n-1) \qquad \text{if} \qquad B_{mad}(n) > B_1 * TB_{mad}(n),$$
$$T_{fi}(n) = A_2 * T_{fi}(n-1) \qquad \text{if} \qquad B_{mad}(n) < B_2 * TB_{mad}(n),$$
$$T_{fi}(n) = T_{fi}(n-1) \qquad \text{otherwise},$$

wherein

$T_{fi}(n)$ is the target encoding time interval or the target time needed to encode the Inter-frame,

A_1 is a parameter wherein $0.80 < A_1 < 1.00$,

A_2 is a parameter wherein $1.00 < A_2 < 1.10$,

B_1 is a parameter wherein $1.00 < B_1 < 2.00$,

B_2 is a parameter wherein $0 < B_2 < 1.00$,

$TB_{mad}(n)$ is the average of $B_{mad}(n)$, and

$B_{mad}(n)$ is related to the average encoding time interval T_{ave} by

$$B_{mad}(n) = \frac{u(n)\max\{T_{ave}(n-1), T_{fi}(n-1)\}}{MAD(n)}$$

wherein
$u(n)$ is the available channel bandwidth,
$T_{ave}(n-1)$ is the average encoding time interval for the Inter-frame, and
$MAD(n)$ is the mean absolute difference between the current frame and the previous frame.

According to the invention, A_1 is preferably set at 0.9, A_2 is preferably set at 1.05, B_1 is preferably set at 1.5, and B_2 is preferably set at 0.25.

The value of the target encoding time interval $T_{fi}(n)$ obtained is preferably further adjusted using the following equation:

$$T_{fi}(n) = \min\left\{\frac{5}{4F_r}, \max\left\{\frac{3}{4F_r}, T_{fi}(n)\right\}\right\}.$$

The target encoding time interval $T_{fi}(n)$ is inversely related to the desired frame rate.

The average encoding time interval is determined using information on an actual encoding time interval for encoding the Inter-frame, the target encoding time interval, and the number of skipped frames due to buffer overflow.

The average encoding time interval is determined using the following equation:

$$T_{ave}(n)=(1-x)T_{ave}(n-1)+\chi*\max\left\{T_c(n),\frac{1}{F_r}-RT_{st}(n-1)\right\}$$

wherein

$T_{ave}(n)$ is the average time interval for encoding the Inter-frame,

χ is a weighting factor,

$T_c(n)$ is the actual time for encoding the Inter-frame,

F_r is a predefined frame rate, and

RT_{st} is further defined as

$$RT_{st}(n)=0 \quad \text{if} \quad \max\{T_c(n),T_{fi}(n)\}<\frac{1}{F_r}-RT_{st}(n-1) \ \text{or} \ N_{post}(n)>0,$$

$$RT_{st}(n)=\max\{T_c(n),T_{fi}(n)\}+RT_{st}(n-1)-\frac{\lfloor(\max\{T_c(n),T_{fi}(n)\}+RT_{st}(n-1))F_r\rfloor}{F_r}$$

otherwise,

wherein $N_{post}(n)$ is the number of skipped frames due to buffer overflow and the $\lfloor a\rfloor$ refers to the largest integer less than *a*.

The use of the sliding window based method for computing $T_{fi}(n)$ has the advantage of reducing the effect of burst noise on the overall performance of the whole encoding process.

This simple method of adjusting the desired frame rate according to the invention is able to keep the quality of Inter-frames in a tolerable range under time-varying channel

bandwidth and sudden motion change without obvious degradation in the perceptual motion smoothness.

The desired frame rate is determined using information on the average encoding time interval $T_{ave}(n)$, and hence based on the available computational resources.

In each GOP, the target buffer level in each frame is predefined in a manner such that the more bits are allocated to the Inter-frames, preferably P-frames nearer to the I-frame of the GOP than the Inter-frames which are further away and belonging to the same GOP. In this way, Inter-frames which are near to the I-frame are encoded with a high quality, and subsequent Inter-frames which are predicted from these high quality Inter-frames are also of a high quality. As a result, the prediction gain based on these Inter-frames is improved.

The target buffer level for the Inter-frame is predefined and determined using the following equation:

$$Target(n) = Target(n-1) - \frac{B_c(t_{i,I}) - \delta * B_s}{N_{gop} - 1} * \sum_{j=0}^{N_{pos}(n-1)+S_c(n-1)} W_{pos}(n+j)$$

wherein

Target(n) is the target buffer level,

N_{gop} is the number of frames in a GOP,

B_s is the buffer size,

B_c is the actual buffer occupancy after the coding of I-frame,

S_c is an average number of frames skipped due to insufficient available computational resources for encoding the Inter-frame according to the desired frame rate, and $W_{pos}(l)$ is the position weight of the l^{th} Inter-frame which satisfies

$$\sum_{l=1}^{N_{gop}-1} W_{pos}(l) = N_{gop} - 1$$

and

$$W_{pos}(1) \le W_{pos}(2) \le \cdots \le W_{pos}(N_{gop} - 1).$$

The average number of skipped frames due to insufficient computational resources is determined based on an instant number of skipped frames $\tilde{S}_c(n)$ due to insufficient computational resources when the Inter-frame is encoded. The instant number of skipped frames due to insufficient computational resources is determined using information on the actual encoding time interval and the target encoding time interval. The determining of the instant number of skipped frames due to insufficient computational resources can be summarized using the following equations:

$$\tilde{S}_c(n) = \lfloor TST(n) * F_r \rfloor$$

wherein TST(n) is further defined as

$$TST(n) = \max\left\{0, \tilde{\tilde{TST}}(n-1) + \max\{T_c(n), T_{fi}(n)\} - \frac{1}{F_r}\right\}$$

and $\tilde{\tilde{TST}}(n-1)$ is defined as

$$\tilde{\tilde{TST}}(n-1) = TST(n-1) - \frac{\lfloor TST(n-1) * F_r \rfloor}{F_r}$$

wherein

T_c is the actual encoding time interval, and F_r is a predefined frame rate.

The average number of skipped frames due to insufficient computational resources is then determined using the following equation:

$$S_c(n) = \lfloor (1-\theta) S_c(n-1) + \theta * \tilde{S}_c(n) \rfloor$$

wherein θ is a weighting factor.

The advantage of using the average number of frames skipped S_c instead of an instant number of skipped frames for computing the target buffer level is that the value of S_c changes slowly. This slow change of S_c coincides with a slow adjustment of a quantization parameter Q used for the encoding process of the video.

It should however be noted that in an alternative embodiment of the invention, the instant number of skipped frames $\tilde{S}_c(n)$ can be used instead of the average number of skipped frames $S_c(n)$ to determine the target buffer level.

In the case when the channel bandwidth is constant, the complexity of each frame the same and the desired frame rate is guaranteed, the target buffer level for the n^{th} Inter-frame in the i^{th} GOP can be simplified to become

$$Target(n) = \frac{u}{F_r} - \frac{B_c(t_{i,I}) - \delta * B_s}{N_{gop} - 1} * W_{pos}(n)$$

As can be seen from the above equation, the target buffer level of the current Inter-frame is greater than the target buffer level of the subsequent Inter-frames. In other words, more bits are allocated to the Inter-frame which is nearer to the I-frame belonging to the same GOP than the Inter-frame which is further away from the I-frame, i.e. from the Intra-frame.

The target bit rate according to a preferred embodiment of the invention is determined based on the average encoding time interval, the average number of skipped frame due to insufficient computational resource, the target buffer level, the available channel bandwidth and the actual buffer occupancy. In particular, the target bit rate according to a preferred embodiment of the invention is determined using the following equation:

$$\tilde{f}(n) = \max\{0, u(t_{n,i}) * \max\{T_{ave}(n-1), T_{fi}(n)\} + (\gamma - 1)(B_c(t_{n,i}) - Target(n))\}$$

wherein

$\tilde{f}(n)$ is the target bit rate,

$t_{n,i}$ is the time instant the n^{th} Inter-frame in the i^{th} GOP is coded, and

γ is a constant.

Since the available channel bandwidth $u(t_{n,i})$ and the average encoding time interval $T_{ave}(n-1)$ are used to determine the target bit rate for the Inter-frame, the bit rate control method according to the invention is adaptive to both the available channel bandwidth and the available computational resources.

The target bit rate for the Inter-frame determined above can be further adjusted by a weighted temporal smoothing using the following equation:

$$f(n) = \max\left\{\frac{u(t_{n,i}) * \max\{T_{ave}(n-1), T_{f,i}(n)\}}{3} + H_{hdr}(n-1), \mu \times \tilde{f}(n) + (1-\mu) \times f(n-1)\right\}$$

wherein

$f(n)$ is the smoothed target bit rate,

μ is a weighting control factor constant, and

$H_{hdr}(n)$ is the amount of bits used for shape information, motion vector and header of previous frame.

It should be noted that in an alternative embodiment, the actual encoding time interval $T_{fi}(n)$ can be used instead of the average encoding time interval T_{ave} (n) for determining the target bit rate. The advantage of using the average encoding time interval T_{ave} instead of T_c for the computation of the target bit rate is that T_{ave} changes slowly. This also coincides with the slow adjustment of the quantization

parameter Q for the encoding process of the video sequence. Also when the actual frame rate is less than the predefined frame rate, i.e.

$$T_{ave} > \frac{1}{F_r} \quad ,$$

more bits are assigned to each frame. Therefore, the possibility of buffer underflow is reduced compared to any existing rate control method, and the utilization of the channel bandwidth is improved.

Once the target bit rate for each Inter-frame is computed, the corresponding quantization parameter for the encoding process can be computed, preferably using the Rate-Distortion (R-D) method described in [5].

In a post-encoding stage of the rate control method according to the invention, a sleeping time of the encoding process is updated using the following equation:

$$ST_c(n) = \max\left\{\frac{1}{F_r} - RT_{st}(n-1) - \max\{T_{fi}(n), T_c(n)\}, 0\right\} + \frac{N_{post}(n)}{F_r}$$

wherein $ST_c(n)$ is the sleeping time of the encoding process. The starting coding time of the next frame is then given by

$$SCT(n) = T_c(n) + SCT(n-1) + ST_c(n)$$

wherein $SCT(n)$ is the starting encoding time. The starting decoding time of the next frame is given by

$$SDT(n) = \frac{\lfloor SCT(n) * F_r \rfloor}{F_r}$$

wherein SDT(n) is the starting decoding time. The starting decoding time is to be sent to a decoder to provide information on the time for decoding each frame of the encoded video sequence.

Three points should be considered when determining the sleeping time $ST_c(n)$ and the starting decoding time SDT(n). No frame is to be encoded twice, the time resolution is $1/F_r$ and necessary time should be elapsed when the buffer is in danger of overflow.

Other objects, features and advantages according to the invention will be presented in the following detailed description of the illustrated embodiments when read in conjunction with the accompanying drawings.

Brief Description of the Drawings

Figure 1 shows a block diagram of the rate control method according to a preferred embodiment of the invention.

Figure 2 shows the channel bandwidth used for each frame of the "weather" and "children" video sequences.

Figure 3 shows the computation time needed to encode each frame of the "weather" and "children" video

sequences using the preferred embodiment of the invention.

Figure 4 shows the comparison of the PSNR for the "weather" video sequence.

Figure 5 shows the comparison of the PSNR for the "children" video sequence.

Figure 6 shows the comparison of the actual buffer occupancy for the "weather" video sequence.

Figure 7 shows the comparison of the actual buffer occupancy for the "children" video sequence.

Detailed Description of a preferred embodiment of the Invention

Fig.1 shows a block diagram of the rate control method according to a preferred embodiment of the invention.

The rate control method according to the invention comprises the following three stages:
the initialization stage,
the pre-encoding stage and
the post-encoding stage.

In step 101, a frame rate F_r is predefined for the encoding process for a Group of Pictures (GOP). Practical issues like the parameters/specifications of the encoder and decoder are to be taken into consideration while choosing a

suitable encoding frame rate at this point. Furthermore, it is not always known whether the hardware on which the video encoding process, including the rate control, is implemented can support the predefined frame rate.

In step 102, the buffer size for the video frames is set based on latency requirements. Before the encoding of the I-frame, the buffers are initialized at $B_s * \delta$ wherein B_s is the buffer size and δ is a parameter defined as $0 \leq \delta \leq 0.5$. The I-frame is then encoded in step 103 using a predefined initial value of quantization parameter Q_0. The encoding of the I-frame in step 103 may be implemented using any of the methods described in [1], [3], [4], [5].

After the I-frame is encoded, the parameters of a Rate-Distortion (R-D) model which is subsequently used to determine a suitable quantization parameter for encoding the corresponding frames of the video are updated in the post-encoding stage (step 104). In a further step 105 of the post-encoding stage, the number of skipped frames due to buffer overflow $N_{post}(n)$ is determined, preferably using the method disclosed in [5].

In step 106, a sleeping time $ST_c(n)$ of the encoding process after the current frame is determined, wherein the sleeping time $ST_c(n)$ is used to determine a starting encoding time SCT(n) for the next frame. The determined starting coding time SCT(n) is then used to determine the starting decoding time SDT(n) of the next frame in step 107, wherein the SDT(n) is transmitted to the decoder.

Once the encoding of the I-frame is completed, the next frame, which is an Inter-frame is encoded using the quantization parameter which was determined in the previous post-encoding stage.

When the channel bandwidth or the statistics of the video contents is varying with time, the quality of each frame of the video sequence will vary significantly if the encoding frame rate is fixed at the predefined frame rate F_r. To avoid this, a target or desired frame rate is determined in the pre-encoding stage according to the available channel bandwidth and any sudden motion change.

An average encoding time interval $T_{ave}(n)$, or the average time interval needed for encoding an P-frame, is determined in step 108. The average encoding time interval $T_{ave}(n)$ is then used to determined a target encoding time interval $T_{fi}(n)$ in step 109. The target encoding time interval $T_{fi}(n)$ is inversely related to the desired frame rate.

The determined desired frame rate is then used to determine a target buffer level for the P-frame in step 110. In step 111, the target buffer level, the actual buffer occupancy, the available channel bandwidth, the desired frame rate and the average encoding time interval T_{ave} are used to determine a target bit rate f(n) for the P-frame.

Based on the target bit rate f(n), bits are allocated to the P-frame in step 112. The corresponding quantization parameter Q is computed as described in [5] in step 113 using the updated R-D model from step 104. The quantization parameter Q is used to encode the P-frame in step 114.

When the next frame is a P-frame, the R-D model is updated again in step 104 of the post-encoding stage and the whole post-encoding and pre-encoding stage is iterated for encoding the next P-frame. If the next frame is an I-frame of a next Group of Pictures (GOP), the encoding process starts again at step 101 for the encoding of the next I-frame.

The implementation of the steps 108 to 111 of the pre-encoding stage and steps 106 and 107 of the post-encoding stage according to the invention will now be described in detail.

After the coding of an i^{th} I-frame, the initial value of the target buffer level is initialized at

$$Target(0) = B_c\left(t_{i,I}\right) \tag{1}$$

wherein

$B_c(t_{i,I})$ is the actual buffer occupancy after the coding of the i^{th} I-frame, and

$t_{i,I}$ is the time instant that the i^{th} I-frame is coded.

To determine the target bit rate of each P-frame of the GOP, the target buffer level for the P-frame needs to be determined. The first step of determining the target buffer level is to determine the desired frame rate. This is achieved by first determining the average encoding time interval of the P-frame $T_{ave}(n)$ using the following equation (step 108):

$$T_{ave}(n) = (1-x)T_{ave}(n-1) + \chi * \max\left\{T_c(n), \frac{1}{F_r} - RT_{st}(n-1)\right\} \quad (2)$$

wherein

χ is a weighting factor,
$T_c(n)$ is the actual time for encoding the P-frame, and
RT_{st} is defined as

$$RT_{st}(n) = 0 \quad \text{if} \quad \max\{T_c(n), T_{fi}(n)\} < \frac{1}{F_r} - RT_{st}(n-1) \quad \text{or} \quad N_{past}(n) > 0, \quad (3)$$

$$RT_{st}(n) = \max\{T_c(n), T_{fi}(n)\} + RT_{st}(n-1) - \frac{\lfloor(\max\{T_c(n), T_{fi}(n)\} + RT_{st}(n-1))F_r\rfloor}{F_r} \quad (4)$$

otherwise,

wherein $\lfloor a \rfloor$ refers to the largest integer less than a.

The weighting factor χ is $0 < \chi < 1$, and is preferably set to a value of 0.125. The initial value of the average encoding time interval $T_{ave}(n)$ is given by

$$T_{ave}(0) = \frac{1}{F_r} \quad (5)$$

and the initial value of $RT_{st}(n)$ is given by

$$RT_{st}(0) = 0 \quad (6)$$

A variable $B_{mad}(n)$ is further defined by the following equation:

$$B_{mad}(n) = \frac{u(n)\max\{T_{ave}(n-1), T_{fi}(n-1)\}}{MAD(n)} \quad (7)$$

wherein

$u(n)$ is the available channel bandwidth, and

$MAD(n)$ is the mean absolute difference between the current frame and the previous frame.

The available channel bandwidth $u(n)$ can be estimated by the method described in [6].

An average value of $B_{mad}(n)$ is then computed using the following equation:

$$TB_{mad}(n) = (1-\xi)TB_{mad}(n-1) + \xi B_{mad}(n) \quad (8)$$

wherein

$TB_{mad}(n)$ is the average value of $B_{mad}(n)$, and

ξ is a weighting factor, preferably at a value of 0.125.

After the value of $TB_{mad}(n)$ is computed, the target encoding time interval $T_{fi}(n)$ can be calculated as below (step 109):

$$T_{fi}(n) = A_1 * T_{fi}(n-1) \text{ if } B_{mad}(n) > B_1 * TB_{mad}(n), \quad (9)$$

$$T_{fi}(n) = A_2 * T_{fi}(n-1) \text{ if } B_{mad}(n) < B_2 * TB_{mad}(n), \quad (10)$$

$$T_{fi}(n) = T_{fi}(n-1) \text{ otherwise.} \quad (11)$$

wherein

A_1 is a parameter wherein $0.80 < A_1 < 1.00$,

A_2 is a parameter wherein $1.00 < A_2 < 1.10$,

B_1 is a parameter wherein $1.00 < B_1 < 2.00$, and
B_2 is a parameter wherein $0 < B_2 < 1.00$.

The value of the target encoding time interval $T_{fi}(n)$ determined from equations (9), (10) or (11) may further be adjusted using the following equation:

$$T_{fi}(n) = \min\left\{\frac{5}{4F_r}, \max\left\{\frac{3}{4F_r}, T_{fi}(n)\right\}\right\} \qquad (12)$$

wherein the initial value of $T_{fi}(n)$ is given by

$$T_{fi}(0) = \frac{1}{F_r} \qquad (13)$$

After the desired frame rate is determined from the inverse of the target encoding time interval $T_{fi}(n)$, the average number of frames skipped due to insufficient computational resources $S_c(n)$ is determined in order to determine the target buffer level.

Two time variables are defined as follow:

$$\widetilde{TST}(n-1) = TST(n-1) - \frac{\lfloor TST(n-1) * F_r \rfloor}{F_r} \qquad (14)$$

$$TST(n) = \max\left\{0, \widetilde{TST}(n-1) + \max\{T_c(n), T_{fi}(n)\} - \frac{1}{F_r}\right\} \qquad (15)$$

wherein the initial value of TST(n) is given by

$$TST(0)=0 \tag{16}$$

An instant number of skipped frame $\tilde{S}_c(n)$ due to insufficient computational resources is then given by

$$\tilde{S}_c(n)=\lfloor TST(n)*F_r\rfloor \tag{17}$$

and the average number of skipped frames due to insufficient computational resources $S_c(n)$ is given by

$$S_c(n)=\lfloor(1-\theta)S_c(n-1)+\theta*\tilde{S}_c(n)\rfloor \tag{18}$$

wherein θ is $0 < \theta < 1$, and is preferably set at a value of 0.125. The initial value of $S_c(n)$ is given by

$$S_c(0)=0 \tag{19}$$

The target buffer level for the P-frame can now be determined using the following equation (step 110):

$$Target(n)=Target(n-1)-\frac{B_c(t_{i,I})-\delta*B_s}{N_{gop}-1}*\sum_{j=0}^{N_{pos}(n-1)+S_c(n-1)}W_{pos}(n+j) \tag{20}$$

wherein

Target(n) is the target buffer level,

N_{gop} is the number of frames in a GOP, and

$W_{pos}(l)$ is the position weight of the l^{th} Inter-frame which satisfies

$$\sum_{l=1}^{N_{gop}-1} W_{pos}(l) = N_{gop} - 1$$

and

$$W_{pos}(1) \le W_{pos}(2) \le \cdots \le W_{pos}(N_{gop}-1) .$$

As the R-D model is not exact, there is usually a difference between the target buffer level for each frame and the actual buffer occupancy. A target bit rate is thus computed for each frame to maintain the actual buffer occupancy to be target buffer level. The target bit rate for each frame is determined by:

$$\tilde{f}(n) = \max\{0, u(t_{n,i}) * \max\{T_{ave}(n-1), T_{fi}(n)\} + (\gamma - 1)(B_c(t_{n,i}) - T\arg et(n))\} \quad (21)$$

wherein

$\tilde{f}(n)$ is the target bit rate,
$t_{n,i}$ is the time instant the n^{th} P-frame in the i^{th} GOP is coded, and
γ is a constant which is $0 < \gamma < 1$, and is preferably set at a value of 0.25 .

Since the available channel bandwidth $u(t_{n,i})$ and the average coding time interval $T_{ave}(n-1)$ are used to determine the target bit rate for each P-frame, the bit rate control method according to the invention is adaptive to the channel bandwidth and the computational resources.

Further adjustment to the target bit rate can be made using the following weighted temporal smoothing equation:

$$f(n) = \max\left\{\frac{u(t_{n,i}) * \max\{T_{ave}(n-1), T_{f,i}(n)\}}{3} + H_{hdr}(n-1), \mu \times \tilde{f}(n) + (1-\mu) \times f(n-1)\right\} \tag{22}$$

wherein

f(n) is the smoothed target bit rate,

μ is a weighting control factor constant which is set preferably at a value of 0.5, and

$H_{hdr}(n)$ is the amount of bits used for shape information, motion vector and header of previous frame.

Once the target bit rate is determined, bits are allocated to each P-frame based on this target bit rate (step 112). The corresponding quantization parameter Q is also calculated (step 113) using the method disclosed in [5]. The corresponding quantization parameter Q is then used for coding the P-frame (step 114).

After the coding of the P-frame is complete, the parameters of the R-D model is updated and the number of skipped frames due to buffer overflow are determined in the post-encoding stage (step 104,105), respectively, using the method disclosed in [5].

In a further step of the post-encoding stage (step 106), the sleeping time of the encoding process after the current frame is determined using the following equation:

$$ST_c(n) = \max\left\{\frac{1}{F_r} - RT_{st}(n-1) - \max\{T_{fi}(n), T_c(n)\}, 0\right\} + \frac{N_{post}(n)}{F_r} \qquad (23)$$

wherein $ST_c(n)$ is the sleeping time of the encoding process.

The starting encoding time of the next frame can then be obtained using the following equation:

$$SCT(n) = T_c(n) + SCT(n-1) + ST_c(n) \qquad (24)$$

wherein SCT(n) is the starting encoding time. The starting decoding time for the next frame can then be obtained using the following equation (step 107):

$$SDT(n) = \frac{\lfloor SCT(n) * F_r \rfloor}{F_r} \qquad (25)$$

wherein SDT(n) is the starting decoding time. The SDT(n) for the next frame is then transmitted to the decoder to decode the next frame at the time indicated by SDT(n).

It should be noted that in the determination of $ST_c(n)$ and SDT(n), no frame is encoded twice, the time resolution is $1/F_r$, and necessary time should be elapsed when the buffer is in danger of overflow.

To demonstrate that the objective of the rate control method according to the invention has been met, the rate control method according to the invention and the rate control method used in the standard MPEG-4 encoding device are

applied to two video sequences, and their performances are compared accordingly.

The two video sequences are referred as "weather" and "children", respectively, and are in the size of QCIF. The predefined frame rate, F_c, is 30 fps (frames per second), and the length of each GOP is 50. The available channel bandwidth and the computation time used for encoding each frame of the video sequence are shown in Fig.2 and Fig.3, respectively.

The actual frame rate is above 17 fps, which is less than the predefined frame rate of 30 fps. The initial buffer fullness is set at $B_s/8$ and the initial quantization parameter Q_0 is set at 15.

Fig.4 and Fig.5 show the Peak Signal-to-Noise Ratio (PSNR) of the "weather" and "children" video sequence using the rate control method according to the invention and the rate control method used in MPEG-4, respectively.

The average PSNR of the "weather" video sequence using the rate control method according to the invention is 34.16 dB, wherein the average PSNR of the "weather" video sequence using the rate control method used in MPEG-4 is 32.6 dB. Similarly, the average PSNR of the "children" video sequence using the rate control method according to the invention is 30.51 dB, wherein the average PSNR of the "children" video sequence using the rate control method used in MPEG-4 is 29.87 dB.

Therefore, it can be seen that the average PSNR of the video sequences using the rate control method according to the invention is higher than using the rate control method of MPEG-4.

Fig.6 and Fig.7 show the actual buffer occupancy for the "weather" and "children" video sequences using the rate control method according to the invention and the rate control method used in MPEG-4, respectively.

As can be seen from Fig.6 and Fig.7, the occurrence of buffer underflow using the rate control method of MPEG-4 is 12 times for the "weather" video sequence and 18 times for the "children" video sequence. There is no buffer underflow for the two videos sequences using the rate control method according to the invention.

The following documents are used in this specification:

[1] H.J.Lee and T.H.Chiang and Y.Q.Zhang. Scalable Rate Control for MPEG-4 Video. IEEE Trans. Circuit Syst. Video Technology, 10: 878-894, 2000.

[2] T.Chang and Y.Q.Zhang. A new rate control scheme using quadratic rate-distortion modeling. IEEE Trans. Circuit Syst. Video Technology, 7: 246-250, 1997.

[3] J. Ribas-Corbera and S.Lei. Rate control in DCT video coding for low-delay communications. IEEE Trans. Circuit Syst. Video Technology, 9: 172-185, 1999.

[4] A.Vetro, H.Sun and Y.Wang. MPEG-4 rate control for multiple video objects. IEEE Trans. Circuit Syst. Video Technology, 9: 186-199, 1999.

[5] Z.G.Li, X.Lin, C.Zhu and F.Pan. A novel rate control scheme for video over the internet. In Proceedings ICASSP 2002, Florida, USA, Vol.2, pp. 2065-2068, May 2002.

[6] Z.G.Li, N.Ling, C.Zhu, X.K.Yang, G.N.Feng, S.Wu and F.Pan. Packetization algorithm for MPEG-4 Fine Granularity Scalability over the internet. In the 3rd workshop and Exhibition on MPEG-4, USA, California, pp. 17-20, June 25-27, 2002.

What is claimed is

1. A method for controlling the rate for encoding a video sequence, wherein the video sequence comprises a plurality of Group Of Pictures, wherein each Group of Picture comprises at least an I-frame and an Inter-frame, the method comprising the following steps for the encoding of each Inter-frame in the Group of Picture:
   - Determining a desired frame rate based on an available bandwidth of a channel which is used for transmitting the video sequence and on available computational resources for the encoding process;
   - Determining a target buffer level based on the desired frame rate and the position of the Inter-frame with respect to the I-frame; and
   - Determining a target bit rate based on the target buffer level and the available channel bandwidth, wherein the target bit rate is used for controlling the rate for encoding the video sequence.

2. The method for rate control according to claim 1, comprising the further steps of:
   - Determining a target encoding time interval for the Inter-frame; and
   - Determining the desired frame rate based on the determined target encoding time interval.

3. The method for rate control according to claim 2, wherein the target encoding time interval for the Inter-frame is determined based on the available channel bandwidth and an average encoding time interval used for

encoding the Inter-frame, wherein the average encoding time interval for the Inter-frame is proportional to the available computational resources for the encoding process.

4. The method for rate control according to claim 3, wherein the target encoding time interval for the Inter-frame is determined using the following equations:

$$T_{fi}(n) = A_1 * T_{fi}(n-1) \quad \text{if} \quad B_{mad}(n) > B_1 * TB_{mad}(n),$$
$$T_{fi}(n) = A_2 * T_{fi}(n-1) \quad \text{if} \quad B_{mad}(n) < B_2 * TB_{mad}(n),$$
$$T_{fi}(n) = T_{fi}(n-1) \quad \text{otherwise,}$$

wherein

- $T_{fi}(n)$ is the target encoding time interval for the Inter-frame,
- A_1 is a parameter wherein $0.80 < A_1 < 1.00$,
- A_2 is a parameter wherein $1.00 < A_2 < 1.10$,
- B_1 is a parameter wherein $1.00 < B_1 < 2.00$,
- B_2 is a parameter wherein $0 < B_2 < 1.00$,
- $TB_{mad}(n)$ is the average of $B_{mad}(n)$, and
- $B_{mad}(n)$ is defined as

$$B_{mad}(n) = \frac{u(n)\max\{T_{ave}(n-1), T_{fi}(n-1)\}}{MAD(n)}$$

wherein

- $u(n)$ is the available channel bandwidth,
- $T_{ave}(n-1)$ is the average encoding time interval for the Inter-frame, and

- MAD(n) is the mean absolute difference between the current frame and the previous frame.

5. The method for rate control according to claim 4, wherein the target encoding time interval is further adjusted by

$$T_{fi}(n) = \min\left\{\frac{5}{4F_r}, \max\left\{\frac{3}{4F_r}, T_{fi}(n)\right\}\right\}.$$

6. The method for rate control according to claim 3, wherein the average encoding time interval for the Inter-frame is determined based on an actual encoding time interval for the Inter-frame.

7. The method for rate control according to claim 6, wherein the average encoding time interval for the Inter-frame is further determined based on the target encoding time interval and the number of skipped frames due to buffer overflow.

8. The method for rate control according to claim 7, wherein the average encoding time interval for the Inter-frame is determined using the following equation:

$$T_{ave}(n) = (1-x)T_{ave}(n-1) + \chi * \max\left\{T_c(n), \frac{1}{F_r} - RT_{st}(n-1)\right\}$$

wherein

- χ is a weighting factor,
- $T_c(n)$ is the actual encoding time,

- F_r is a predefined frame rate, and
- RT_{st} is further defined as

$$RT_{st}(n)=0 \quad \text{if} \quad \max\{T_c(n),T_{fi}(n)\}<\frac{1}{F_r}-RT_{st}(n-1) \ \text{or} \ N_{post}(n)>0,$$

$$RT_{st}(n)=\max\{T_c(n),T_{fi}(n)\}+RT_{st}(n-1)-\frac{\lfloor(\max\{T_c(n),T_{fi}(n)\}+RT_{st}(n-1))F_r\rfloor}{F_r}$$

otherwise,

wherein $N_{post}(n)$ is the number of skipped frames due to buffer overflow.

9. The method for rate control according to claim 5, wherein the target buffer level is determined such that an Inter-frame which is nearer to the I-frame in the GOP has a higher target buffer level compared to another Inter-frame which is further from the I-frame belonging to the same GOP.

10. The method for rate control according to claim 9, wherein the target buffer level is determined using the following equation:

$$Target(n)=Target(n-1)-\frac{B_c(t_{i,I})-\delta*B_s}{N_{gop}-1}*\sum_{j=0}^{N_{post}(n-1)+S_c(n-1)}W_{pos}(n+j)$$

wherein

- Target(n) is the target buffer level,
- N_{gop} is the number of frames in a GOP,
- B_s is the buffer size,
- B_c is the actual buffer occupancy,

- S_c is an average number of skipped frames due to insufficient available computational resources for encoding the Inter-frame according to the desired frame rate, and
- $W_{pos}(l)$ is the position weight of the l^{th} Inter-frame which satisfies

$$\sum_{l=1}^{N_{gop}-1} W_{pos}(l) = N_{gop} - 1$$

and

$$W_{pos}(1) \le W_{pos}(2) \le \cdots \le W_{pos}(N_{gop}-1).$$

11. The method for rate control according to claim 10, wherein the average number of skipped frames due to insufficient available computational resources for encoding the Inter-frame according to the desired frame rate is determined based on an instant number of skipped frames due to the insufficient computational resources while encoding the Inter-frame.

12. The method for rate control according to claim 11, wherein the instant number of skipped frames due to insufficient computational resources is determined based on the actual encoding time interval and the target encoding time interval.

13. The method for rate control according to claim 12, wherein the instant number of skipped frames is determined using the following equation:

$$\tilde{S}_c(n) = \lfloor TST(n) * F_r \rfloor$$

wherein TST(n) is further defined as

$$TST(n) = \max\left\{0, \tilde{T}\tilde{S}\tilde{T}(n-1) + \max\{T_c(n), T_{fi}(n)\} - \frac{1}{F_r}\right\}$$

and $\tilde{T}\tilde{S}\tilde{T}(n-1)$ is defined as

$$\tilde{T}\tilde{S}\tilde{T}(n-1) = TST(n-1) - \frac{\lfloor TST(n-1) * F_r \rfloor}{F_r}$$

wherein

- $\tilde{S}_c(n)$ is the instant number of skipped frames due to insufficient computational resources,
- $T_c(n)$ is the actual encoding time interval, and
- F_r is a predefined frame rate.

14. The method for rate control according to claim 13, wherein the average number of skipped frames due to insufficient computational resources is determined using the following equation:

$$S_c(n) = \lfloor (1-\theta) S_c(n-1) + \theta * \tilde{S}_c(n) \rfloor$$

wherein

- θ is a weighting factor.

15. The method for rate control according to claim 14, wherein the target bit rate is determined based on the

average encoding time interval for the Inter-frame, the average number of skipped frames due to insufficient computational resources, the target buffer level, the available channel bandwidth and actual buffer occupancy.

16. The method for rate control according to claims 8 and 15, wherein the target bit rate is determined using the following equation:

$$\tilde{f}(n) = \max\{0, u(t_{n,i}) * \max\{T_{ave}(n-1), T_{fi}(n)\} + (\gamma - 1)(B_c(t_{n,i}) - Target(n))\}$$

wherein

- $\tilde{f}(n)$ is the target bit rate,
- $t_{n,i}$ is the time instant the n^{th} Inter-frame in the i^{th} GOP is coded, and
- γ is a constant.

17. The method for rate control according to claim 16, wherein the target bit rate is further adjusted by a weighted temporal smoothing using

$$f(n) = \max\left\{\frac{u(t_{n,i}) * \max\{T_{ave}(n-1), T_{f,i}(n)\}}{3} + H_{hdr}(n-1), \mu \times \tilde{f}(n) + (1-\mu) \times f(n-1)\right\}$$

wherein

- f(n) is the smoothed target bit rate,
- μ is a weighting control factor constant, and
- $H_{hdr}(n)$ is the amount of bits used for shape information, motion vector and header of previous frame.

18. The method for rate control according to claim 1, further comprising the following steps:
    - Determining a sleeping time of each frame after the frame is coded,
    - Determining a starting encoding time of each of the frame based on the computed sleeping time,
    - Determining a starting decoding time of a next frame based on the computed starting encoding time, and
    - Transmitting the determined starting decoding time to a decoder which is designed for decoding the video sequences.

19. The method for rate control according to claim 18, wherein the sleeping time is determined according to the following formula:

$$ST_c(n) = \max\left\{\frac{1}{F_r} - RT_{st}(n-1) - \max\{T_{fl}(n), T_c(n)\}, 0\right\} + \frac{N_{post}(n)}{F_r}$$

wherein $ST_c(n)$ is the sleeping time of the coding process.

20. The method for rate control according to claim 19, wherein the starting encoding time is determined according to the following formula:

$$SCT(n) = T_c(n) + SCT(n-1) + ST_c(n)$$

wherein SCT(n) is the starting encoding time.

21. The method for rate control according to claim 20, wherein the starting decoding time is determined according to the following formula:

$$SDT(n) = \frac{\lfloor SCT(n) * F_r \rfloor}{F_r}$$

wherein SDT(n) is the starting decoding time.

22. An apparatus for controlling the rate for encoding a video sequence, wherein the video sequence comprises a plurality of Group Of Pictures, wherein each Group of Picture comprises at least and I-frame and an Inter-frame, the apparatus comprises a processing unit being adapted to perform the following steps for the encoding of each Inter-frame in the Group of Picture:

- Determining a desired frame rate based on an available bandwidth of a channel which is used for transmitting the video sequence and on available computational resources for the encoding process;
- Determining a target buffer level based on the desired frame rate and the position of the Inter-frame with respect to the I-frame; and
- Determining a target bit rate based on the target buffer level and the available channel bandwidth, wherein the target bit rate is used for controlling the rate for encoding the video sequence.

23. A video encoding device for controlling the rate for encoding a video sequence, wherein the video sequence comprises a plurality of Group Of Pictures, wherein each

Group of Picture comprises at least and I-frame and an Inter-frame, the encoding device comprises a processing unit being adapted to perform the following steps for the encoding of each Inter-frame in the Group of Picture:

- Determining a desired frame rate based on an available bandwidth of a channel which is used for transmitting the video sequence and on available computational resources for the encoding process;
- Determining a target buffer level based on the desired frame rate and the complexity and the position of the Inter-frame with respect to the I-frame; and
- Determining a target bit rate based on the target buffer level and the available channel bandwidth, wherein the target bit rate is used for controlling the rate for encoding the video sequence.

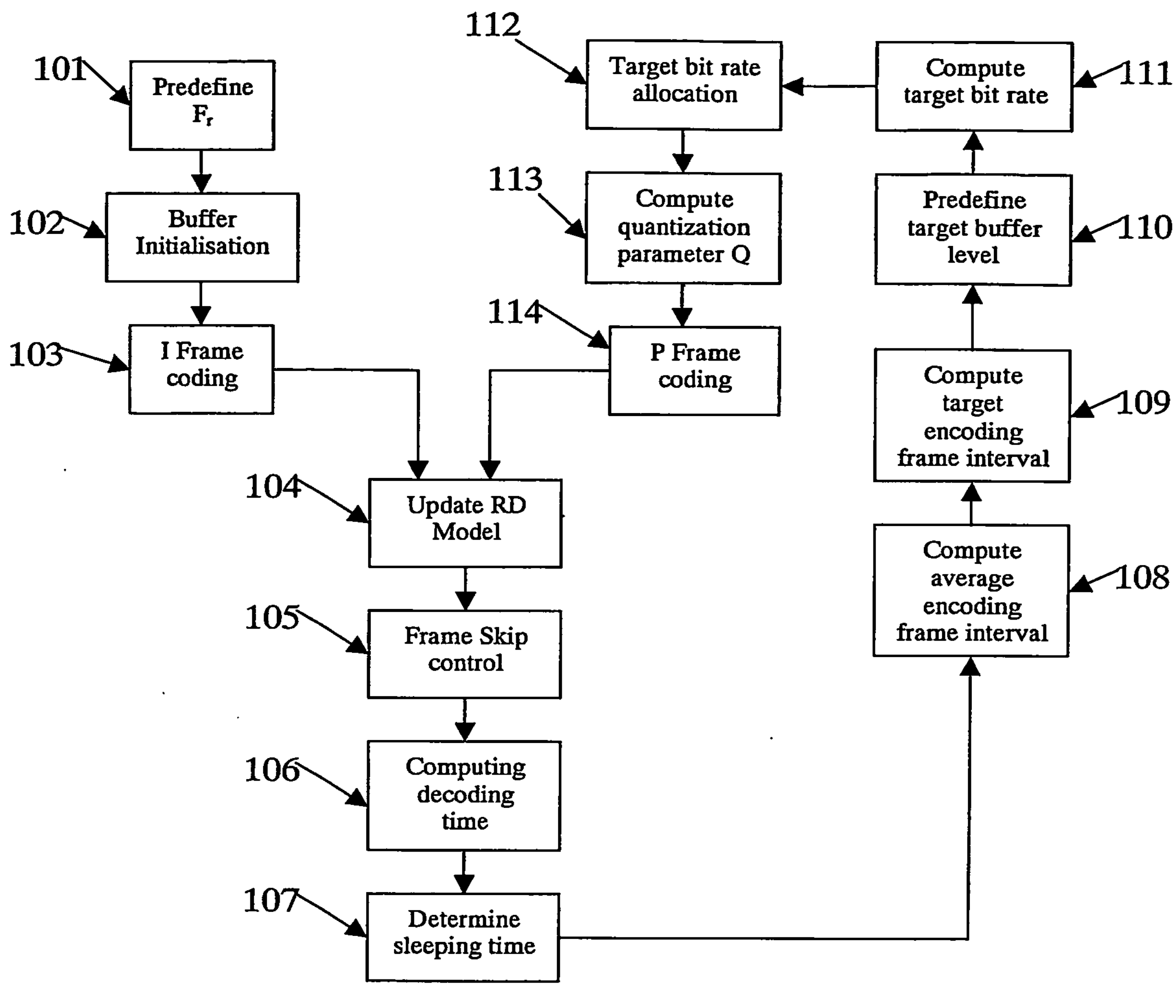
101
Predefine F_r
102
Buffer Initialisation
103
I Frame coding
104
Update RD Model
105
Frame Skip control
106
Computing decoding time
107
Determine sleeping time
112
Target bit rate allocation
113
Compute quantization parameter Q
114
P Frame coding
111
Compute target bit rate
110
Predefine target buffer level
109
Compute target encoding frame interval
108
Compute average encoding frame interval

FIG 1

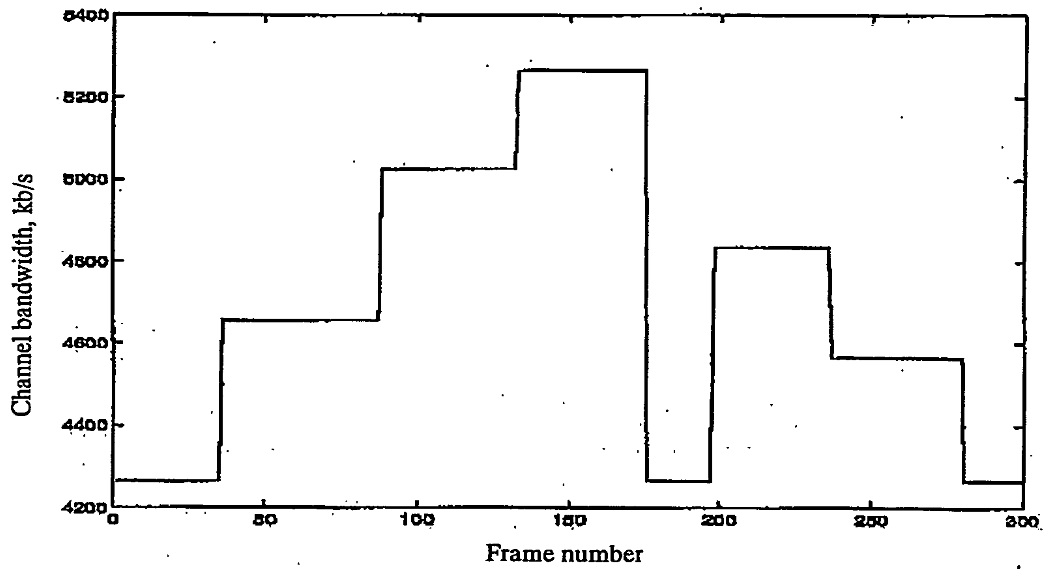
Channel bandwidth, kb/s
5400
5200
5000
4800
4600
4400
4200
0
50
100
150
200
250
300
Frame number

FIG 2

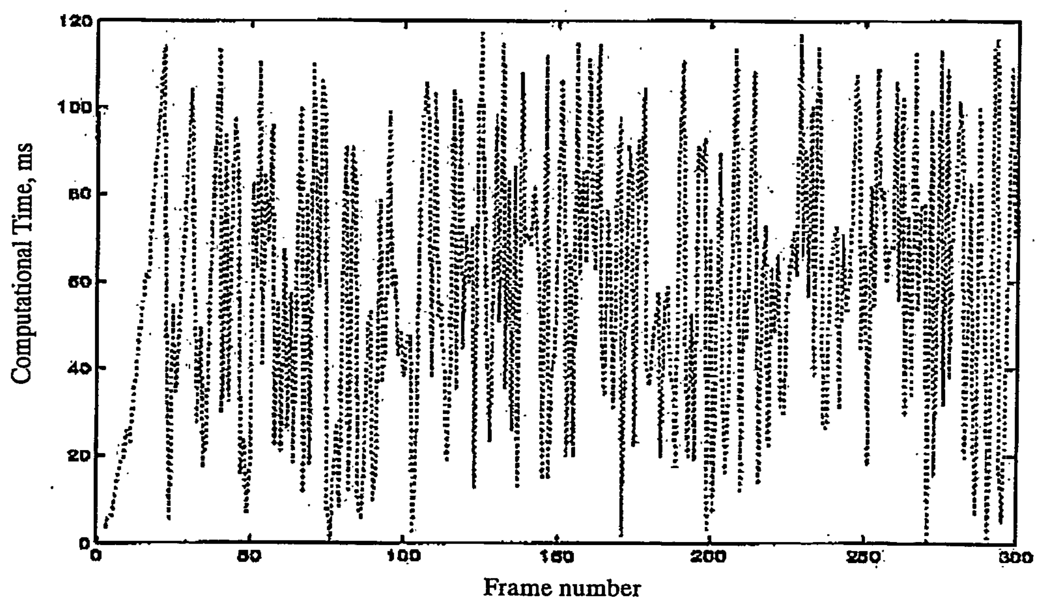
Computational Time, ms
120
100
80
60
40
20
0
0
50
100
150
200
250
300
Frame number

FIG 3

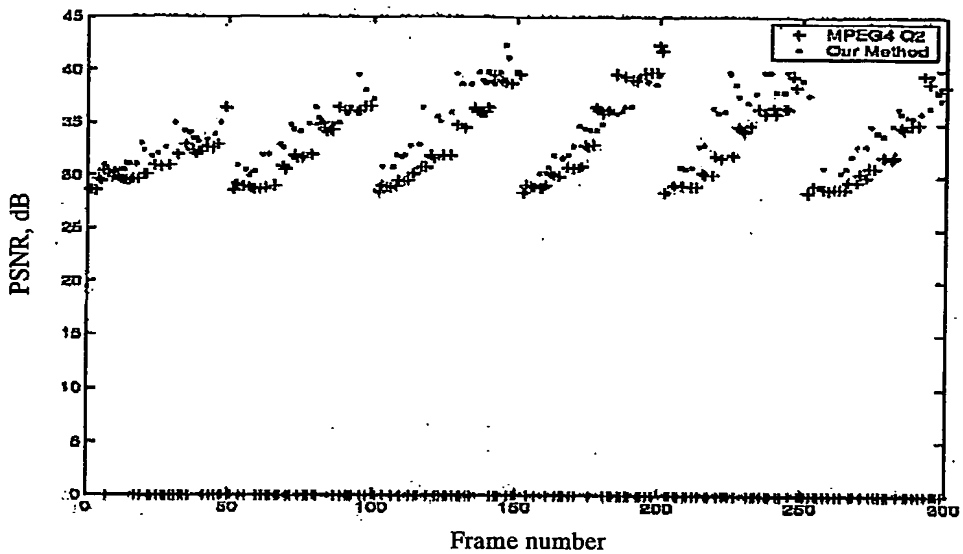
MPEG4 Q2
Our Method
PSNR, dB
Frame number
0
50
100
150
200
250
300
0
5
10
15
20
25
30
35
40
45

FIG 4

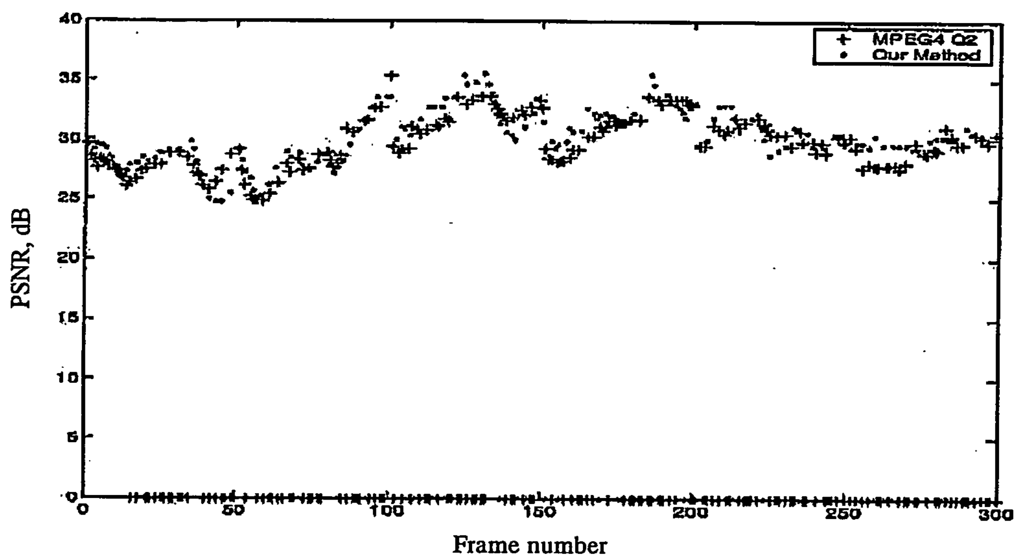
MPEG4 Q2
Our Method
PSNR, dB
Frame number
0
50
100
150
200
250
300
0
5
10
15
20
25
30
35
40

FIG 5

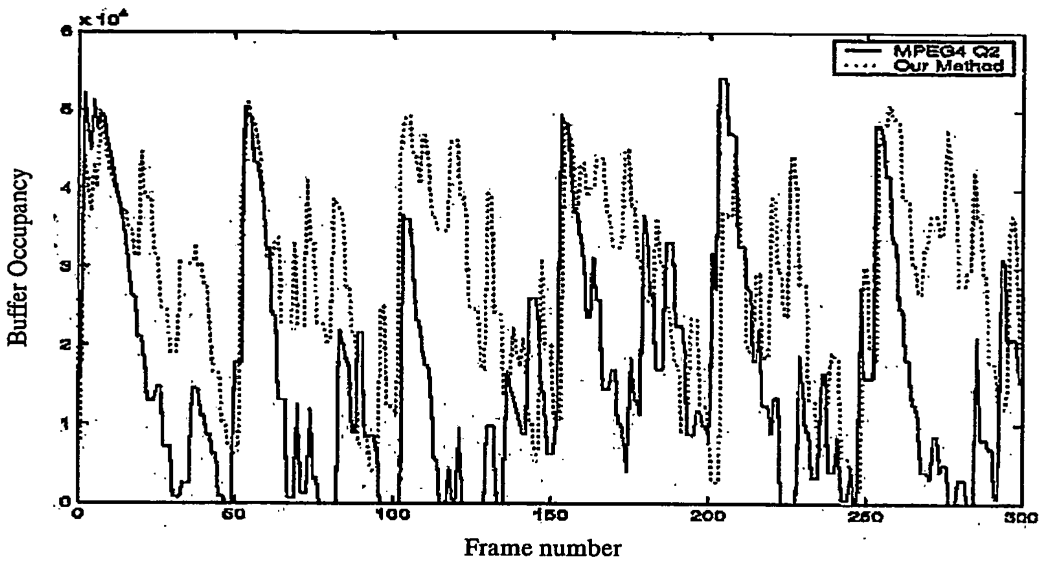
x 10^4
MPEG4 Q2
Our Method
Buffer Occupancy
Frame number
0
50
100
150
200
250
300
1
2
3
4
5
6

FIG 6

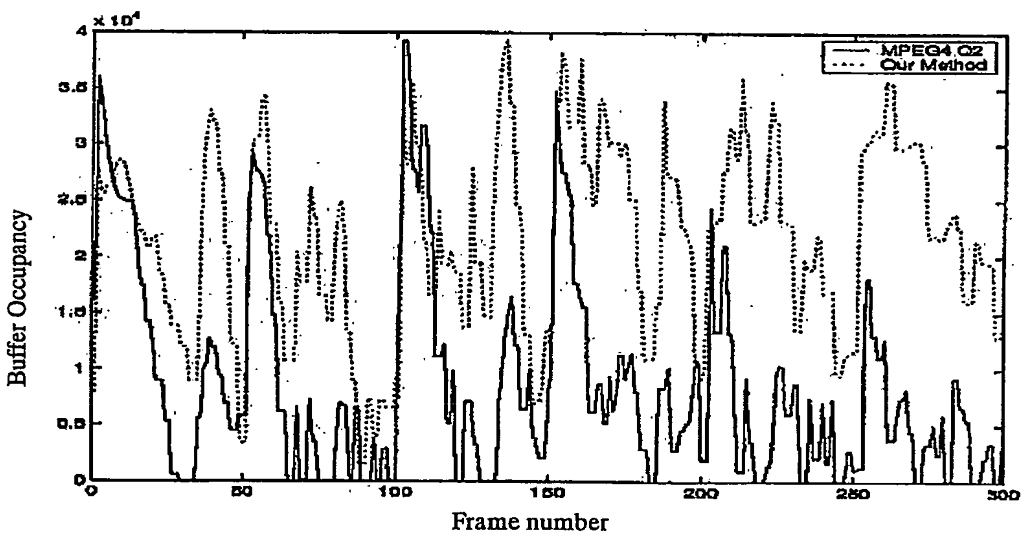
x 10^4
MPEG4 Q2
Our Method
Buffer Occupancy
Frame number
0
50
100
150
200
250
300
0.5
1
1.5
2
2.5
3
3.5
4

FIG 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SG02/00206

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl. [7]: H04N 7/50

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC: AS ABOVE

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
WPAT (rate, control, encod+, decod+, frame)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	"Optimal Multidimensional Bit-Rate Control for Video Communication" (Reed et al.) IEEE TRANSACTIONS ON IMAGE PROCESSING, Vol. 11, No. 8, pp 873-885 August 2002 Whole document	1,22,23
Y	US 6091776 A (LINZER) 18 July 2000 Abstract, figures, column 2 line 48 to column 3 line 36 , column 10 lines 21-28	1,22,23
Y	WO 99/52295 A (SARNOFF CORPORATION) 14 October 1999 Abstract, figures, paragraph bridging pages 1 and 2, page 7, page 10 lines 4-16	1,22,23

[X] Further documents are listed in the continuation of Box C [X] See patent family annex

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 October 2002	15 OCT 2002

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/SG02/00206

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	"Minimax Frame Rate Control Using a Rate-Distortion Optimized Wavelet Coder" (Yang & Hemami) Proc. IEEE Int. Conference on Image Processing October 1999 See Introduction (Section 1) and Adaptive Adjustment (Section 3.2)	1,22,23
Y	US 5 872 598 A (LEGALL et al.) 16 February 1999 Whole document	1,22,23
Y	US 5 717 464 A (PERKINS et al.) 10 February 1998 Whole document	1,22,23
A	US 5 134 476 A (ARAVIND et al.) 28 July 1992 Abstract, claims	1,22,23

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/SG02/00206

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
US	6091776	NONE					
WO	9952295	EP	1068735	EP	1068736	EP	1078531
		US	6167088	US	2002064228	US	6430317
		US	6434196	WO	9952296	WO	9952297
		AU	19470/99	AU	20140/99	EP	1042734
		EP	1042735	US	6408101	WO	9934330
		WO	9934331	US	6208692		
US	5872598	NONE					
US	5717464	NONE					
US	5134476	NONE					

END OF ANNEX